# Chaos, Complexity and Deterrence

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Core Course 5605
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April 19, 2000

The Advent of Chaos

Chaos theory in the West (considerable work on chaos was also conducted in the Soviet Union) developed from the 1960s work of meteorologist Edward Lorenz. Lorenz developed a simple meteorological model based on differential equations. When he ran his model on a computer, Lorenz discovered that a very small difference (less than one part in one thousand) in the initial conditions led to large changes in the weather predicted by his model over time.[1] This discovery, sensitivity to initial conditions, is one of the fundamental characteristics of chaos theory. Lorenz went on to explore some of the implications of his discovery and published a seminal paper, *Deterministic Nonperiodic Flow,* in 1963. Over the past few decades, chaos theory has been used widely in the natural sciences. More recently, it has also begun to be applied to the social sciences as well. However, as sometimes happens with trendy concepts from the natural sciences (James Gleick's excellent 1987 popular work, *Chaos*, did much to popularize the concept), chaos theory, often poorly understood, has been stretched and mangled in order to force fit it to social phenomena where its use is inappropriate.[2] Nevertheless, despite the excesses, chaos theory has legitimate applications in the social sciences. Mathematical concepts and formulas, for example, have sometimes been found to be relevant in totally different fields. As physiologist and author Jared Diamond wrote of population geneticist Luigi Luca Cavalli-Sforza's talent for extracting interesting conclusions from unusual data, Cavalli-Sforza recognizes "that there are only a few basic

[1] See Joe Pritchard, The Chaos Cookbook - A Practical Programming Guide, Second Edition (Butterworth-Heinemann, Oxford, England, 1996), p 109, and James Gleick, Chaos, (Viking, New York, New York, 1987), pp11-31.

types of useful mathematical models, that one can thus reuse the same model in different fields with just small changes, and hence that the key step is to recognize good analogies." [3]

Chaos Theory Defined

Before turning to the question of the applicability of chaos to deterrence theory, we must define the concept. What is chaos theory exactly? According to one definition, "Chaos theory is the qualitative study of unstable aperiodic behavior in deterministic nonlinear dynamical systems."[4] With this definition, we can draw several conclusions about the characteristics of chaos. First, that the system is dynamical, means that it changes over time. Second, that the behavior of the system is aperiodic and unstable means that it does not repeat itself. Third, although chaotic behavior is complex, it can have simple causes.[5] Fourth, because the system is nonlinear, it is, as we have already seen, sensitive to initial conditions. (Nonlinearity means that the output of the system is not proportional to the input and that the system does not conform to the principle of additivity, i.e., it may involve synergistic reactions in which the whole is not equal to the sum of its parts.[6]) Fifth, because the system is deterministic, chaotic behavior is not random even though its

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[2] For examples of how chaos has been "applied" to such topics as love and tort negotiations, see Roger Rosenblatt, My Arbitrary Valentine, *Time* Magazine, Feb. 15, 1999, and Richard G. Halpern, Opening a new Door to Negotiation Strategy, *Trial* Magazine, June 1999, pp 22-29.
[3] Jared Diamond, The Golden Phonebook, book review of Genes, Peoples, and Languages, by Luigi Luca Cavalli-Sforza, in *New York Review of Books*, April 13, 2000.
[4] Stephen Kellert, In the Wake of Chaos: Unpredictable Order in Dynamical Systems (Chicago, University of Chicago Press, 1993), cited in Crayton Bedford, The Case of Chaos, in *Mathematics Teacher* Magazine, April 1998.
[5] Garnett P. Williams, Chaos Theory Tamed (Joseph Henry Press, Washington, D.C. 1997), p 7.
[6] Alan Beycheren,Clausewitz, Nonlinearity, and the Unpredictability of War, in *International Security*, Winter 1992, p 62.

aperiodicity and unpredictability may make it appear to be so.[7] On the other hand, because of the instability, aperiodicity, and sensitivity to initial conditions, the behavior of chaotic systems is not predictable even though it is deterministic. A final feature of chaos, although not included in the above definition, is that of iteration or feedback, in which the output of the system is used as the input in the next calculation.[8]

Systems may display both chaotic and non-chaotic behavior depending on the control parameters used. An example is the logistic equation, first devised in 1845, which provides a model for changes in population over time.[9] The equations is as follows:

$$x_{t+1} = kx_t(1 - x_t)$$

In this equation, x is the population, k (the control parameter) is the rate of population growth, t is the initial time period, and t+1 is the subsequent period. The element (1-x) in the equation establishes a practical limit to population growth, a sensible constraint given the existence of famine, disease, and birth control in the real world. When the control parameter is less than three, this simple system converges towards an equilibrium point, regardless of the initial population level. When the control parameter has a value between 3 and about 3.57, the system (i.e., the population) converges not on one but on an increasing number of values, which doubles successively from two to four to eight, and so forth. Eventually, when the control variable falls between 3.57 and 4.0, the system moves into chaos, where the population continues to vary erratically. At higher levels of k, the system can display either chaotic or non-chaotic behavior.

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[7] Gleick, op cit., p 306.
[8] Pritchard, op cit., p 32.
[9] The logistic equation is a frequently-used example to illustrate chaos theory. See Williams, op cit., pp161-173, and Pritchard, op cit., pp 43-52.

## Complexity

Another kind of behavior closely linked to chaos is complexity. A complex system is one in which numerous independent elements continuously interact and spontaneously organize and reorganize themselves into more and more elaborate structures over time.[10] Complexity is characterized by: a) a large number of similar but independent elements or agents; b) persistent movement and responses by these elements to other agents; c) adaptiveness so that the system adjusts to new situations to ensure survival; d) self-organization, in which order in the system forms spontaneously; e) local rules that apply to each agent; and f) progression in complexity so that over time the system becomes larger and more sophisticated. As with chaos, the behavior of self-organizing complex systems cannot be predicted, and they do not observe the principle of additivity, i.e., their components cannot be divided up and studied in isolation. Complex systems can naturally evolve to a state of self-organized criticality, in which behavior lies at the border between order and disorder. Again, the same system can display order, chaos, and self-organizing complexity, depending on the control parameters.

## Chaos/Complexity and the International System

What, then, is the applicability, if any, of chaos theory to strategic thought in general and to deterrence in particular? First, in a metaphorical sense, the theory seems apt in reminding us that actions can have unforeseen consequences and that war can be an unpredictable affair. Certainly, Clausewitz seems to have had an uncanny prescience of

chaos theory in his description of war.[11] In addition, the concept of self-organizing complexity seems to offer a highly accurate description of the international order as a continuously changing, self-adapting system of independent agents (nation-states) progressing into increasingly complexity. This model seems particularly appropriate, given the increasing complexity of the international system since the end of the Second World War resulting from the growing number of independent international and transnational actors. But beyond the metaphorical, can chaos/complexity theory be used in the field of strategy as "as a mathematical model to which to fit the data, in order to extract conclusions of interest"?[12] This paper argues that there is in fact a practical, if limited, applicability of chaos and complexity theory to strategy in general and to deterrence in particular.

First, as Saperstein[13] points out, although chaos by definition cannot be predictive, we can through simulations determine the control parameters under which a system is likely to display chaotic behavior. Chaotic behavior per se does not mean that war will occur, but the unpredictability of the behavior means that we cannot control the system. As a result, the mechanisms in place to prevent war may fail to work as intended, thereby making an outbreak of war more likely. On the other hand, non-chaotic behavior is more predictable and therefore more controllable. Again, this does not mean that war cannot break out in a non-chaotic system, only that, at least to some extent, one can predict

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[10] This section on complexity draws from Williams, op cit., p 234.
[11] For an excellent analysis of Clausewitz and the nonlinearity of war, see Beyerchen, op cit.
[12] Diamond, op cit.
[13] Alvin Saperstein, The Prediction of Unpredictability: Applications of the New Paradigm of Chaos in Dynamical Systems to the Old Problem of the Stability of a System of Hostile Nations, in L. douglas Kiel and Euel Elliott, Editors, Chaos Theory in the Social Sciences: Foundations and Applications, (University of Michigan Press, Ann Arbor, 1996), pp 139-163.

whether a particular path is more or less likely to lead to war and act, or prepare, accordingly. To go back to field that spawned chaos theory, in meteorology, weather forecasters can gain a notion of the accuracy of their predictions by feeding different, but closely similar, sets of data into their computer models. If the output is similar, the forecasters can have some confidence that the system is stable and that their forecasts are likely to be correct. If, on the other hand, the output varies significantly from one input to the next, then chaos is at play and the forecasters can reduce the confidence intervals of their predictions or do away with them altogether.[14]

Saperstein uses this "predicting unpredictability" approach and simple, nonlinear mathematical models to conclude that a tripolar world is more unstable than a bipolar one, that democratic nations are more likely to be peaceful than non-democratic ones, and that a world in which nation-states act to safeguard their security via a balance-of-power alliance system is more stable than one in which countries act alone[15]. In each case, he assumes that the greater the range of parameters in which chaos reigns, the greater the instability of the system.

## Chaos/Complexity Theory and Deterrence

During the Cold War, deterrence was extraordinarily successful, despite one or two close calls, in preventing a major war. Historically, however, deterrence has worked much less well. It may be that the Cold War, with its bipolar simplicity, strong command and

[14] Pritchard, op cit., p 176.
[15] Saperstein, in Kiel and Elliott, op cit., pp 162-3.

control systems on both sides, and the threat of mutual, nuclear annihilation represented an extreme case of deterrence, the likes of which we may not soon see again. Certainly, deterrence has broken down more often since the end of the Cold War than during it. (That deterrence is working less well now may also be due in part to our willingness to become involved in conflicts, e.g., in Yugoslavia, which we would have avoided during the Cold War.) Can chaos theory suggest any ways of making deterrence more effective in the future? If we assume the international system to be in a state of self-organizing criticality, then we can consider that war, which is brought about by a breakdown in deterrence, is an instance in which at least parts of the system spill over into chaos.

Deterrence does have characteristics which are consistent with chaotic behavior. First, as political scientist Colin Gray points out, deterrence is nonlinear.[16] If 50 ICBMs "buy" a certain amount of deterrent, it is not clear that 100 ICBMs will be twice as deterrent. Second, as Gray also points out, deterrence is interactive between two or more nation states and characterized by feedback. And the effectiveness of deterrence has at times proven unpredictable. If deterrence as a system can slide into chaos, we can, borrowing from Saperstein, conclude that we should try to avoid (although avoidance may not always be an option) those conditions that lead to chaotic behavior in the system since it is under those conditions that deterrence can break down unpredictably and lead to war.

Of course, in one sense, if we accept (and we should) that war is inherently chaotic and hence unpredictable, then the threat of war by a deterring country against a would-be aggressor is itself uncertain. In this sense, deterrence can never be perfect or totally

predictable. But can chaos apply to a deterrent system itself? To test this question empirically, we need to first formulate a simple model and to test that model to discover if it displays chaotic behavior and, if so, under what conditions. Naturally, reality will be more complicated than our simple model, but, as Saperstein points out, chaotic behavior does not disappear as we add new variables to a system.[17] On the contrary, regions of stability tend to shrink as variables are added. We must also quantify the data relevant to our model. It is not certain, however, that this can be done in a meaningful way and some trial and error experimentation will be necessary to see if quantification works in practice.

## A Simple Model of Chaos and Deterrence

As one example, of a simple model, we can begin with the classic formulation that deterrence is a function of will and capability. In this case, will does not represent actual will, but will as perceived by one's potential adversaries. We can also posit that capability, beyond a certain minimum level, is relative to the capability of one's potential adversaries'. Finally, we can assume that our ability to deter potential adversaries is based in part on our adversaries' ability to deter us. In other words, the more deterred we are, the less likely to be deterred is our adversary. For greater simplicity and clarity, we will assume only one potential adversary in our model although, in the real world there are, of course, at least several. With these assumptions, our model is defined by the following equations:

[16] Lecture by Dr. Colin Grey to National War College, March 20, 2000.

$$d_{y_{t+1}} = (w_x)(c_{x_t})(1 - c_{x_t}) - d_{x_t}$$

and

$$d_{x_{t+1}} = (w_y)(c_{y_t})(1 - c_{y_t}) - d_{y_t}$$

Where d is deterrence of countries y or x in the following time period, t+1, w is the perceived will of the deterring country, x, c is the capability of x in the previous period, and the final d is the deterrence of x in the previous period. Note the inclusion of the element (1-c). As with the logistic equation, this term is there to place a limit on the level of military capability, which is constrained for economic and technological reasons. In addition, since we assumed that the capability of one country is based in part of the past capability of a potential adversary, we must add two more equations:

$$c_{y_{t+1}} = (a)(c_{x_t})(1 - c_{x_t}) + b$$

and

$$c_{x_{t+1}} = (a)(c_{y_t})(1 - c_{y_t}) + b$$

Where a is a parameter reflecting a country's propensity to react to changes in a potential adversary's military capability and b represents a minimum level of military capability. Again, the term 1-c is added to reflect real-world constraints on military capability. Using these equations, we can run them on a computer and determine when behavior in the system becomes chaotic. It is the areas of chaotic behavior that should be avoided. Of course, the chaotic regions will vary depending on the precise model that we use and on how we quantify the data. But most important of all, and this follows from the discussion above, the area of chaos will be determined by the control parameter. In this case, the control parameter is w, the perceived will of the deterring country and of its potential adversary or adversaries.

[17] Saperstein, in Kiel and Elliott, op cit., p 150.

That will is the key element in the equation, makes intuitive sense. Not only is it the control parameter in our model, in a world in which weapons of mass destruction (WMD) are proliferating, as in ours, relative military capability may become less important than absolute capacity. In other words, even though the U.S. may continue to retain an overwhelming military capability, which ensures, for most practical purposes, that we will prevail despite the chaotic uncertainty of war, other countries may choose to rely on the threat of inflicting unacceptable damage, asymmetrically, on the United States or its allies as a deterrent, rather than attempting to acquire the capability to defeat us militarily. Such an eventuality is consistent with our simple model, which takes into account not only relative, but also absolute, capabilities.

Influencing the Control Parameter

If the control parameter, i.e., ours and our potential adversaries' will, is key, how, then, do we affect that parameter? We have two options. First, we can focus on our adversary's perception of our own will. This would rely on diplomacy, both public and private, and on our past demonstrations of will. In the post-Cold War era, the U.S. record in this regard is mixed. Although we have, on several occasions, been willing to go to war and to win, our victories have never been total. In particular, our adversaries have generally (with the exception of Manuel Noriega in Panama) remained in power despite their defeat. Moreover, our victories have been relatively bloodless, at least on our side, raising questions about staying power should we begin to sustain high casualties. Thus, our perceived will is not as strong as it might be.

The other way of influencing the control parameter is to exercise an impact on our potential adversaries' will. We have already alluded to the influence that our adversaries may have on us through WMD even though their capabilities may clearly fall below the level required to defeat us militarily. Similarly, we may try to work on our adversaries by ratcheting up the level of pain inflicted on them as a result of any aggression on their part. This approach may be particularly effective with despots, who may be relatively immune to threats on the populations of their countries, but who may be more "receptive" to threats against their own livelihoods or interests. Again, this is an area where U.S. actions tend to fall short, as we often apply sanctions which hurt the general populations of adversary countries but which seldom affect their leadership.

## Conclusion

The jury is still out on the applicability of chaos theory to deterrence. While we can create models, as ours above, whose equations display chaotic behavior, it is not clear that deterrence systems work that way in practice or that attempts at quantifying data are accurate or effective. And we should be wary of overreaching and trying to do more with chaos than the theory is able to deliver. Nevertheless, deterrence shows sufficient characteristics of chaos and complexity that it is well worth formulating quantitative deterrence models and to test these for the presence of chaos. It seems likely that such systems will display chaotic behavior under certain parameters and thereby provide useful information about how to avoid the zones of chaos or at least how to be prepared for the worst if we do enter into them.

In addition, in a larger sense, chaos and complexity theory are metaphorically useful in that they offer lessons in how to think about the international system and strategic issues. The theory reminds us to remain flexible and prepare for the unexpected and, if the international system is indeed one of self-organizing complexity, to accept that our ability to control the international order is limited.  That, in itself, is well worth remembering.